

51
16501
51-105-47
451-11

INCHWORM MOTOR®

A CASE HISTORY AS
REPORTED BY THE
INDUSTRIAL PRESS OF
THE NATION

- The Iron Age
- American Machinist
- Steel
- Factory Equipment & Production
- The Tool Engineer
- Electrified Industry
- Aeronautical Procurement
- Metfax
- Automation
- New Equipment Digest
- Machine and Tool Blue Book
- Industrial Machinery News
- Tooling & Production Magazine
- Electromechanical Design



Airborne Instruments Laboratory
INCORPORATED

MINEOLA, LONG ISLAND, NEW YORK

Introduction to



AIRBORNE INSTRUMENTS LABORATORY, Inc. (AIL) is an organization engaged in the development and manufacture of electronic and electromechanical equipment. Activities range from basic research to medium-quantity production, and include a large proportion of work for the U. S. military services.

Total personnel exceeds 1500, of whom approximately 350 are graduate engineers. Skills are well balanced between development and manufacturing activities, thus making it possible to carry each program through all of its steps, beginning with basic investigation of techniques and ending in the manufacture of substantial quantities of the final equipment.

Physical facilities include a series of well-equipped research laboratories, model shops, manufacturing areas, a library, an instrument calibration and repair shop, etc. Total plant area is approximately 220,000 square feet, of which 160,000 square feet is devoted exclusively to manufacturing.

Since its founding in 1945, AIL has established a reputation for both business integrity and quality of product. Some of the more noteworthy AIL developments include radar Moving Target Indicators, the Cyt analyzer for automatic scanning of tissue samples as an aid in early detection of cancer, equipment for radio astronomy, the ASDE radar for observation of airport surface traffic, the Stripline printed waveguide, and a large number of security-classified military developments.

For the past three years, AIL has made its talents and facilities available to assist manufacturing organizations in connection with automation and similar problems. In this brochure, we take pleasure in presenting a case history, on AIL's INCHWORM motor as reported by the industrial press of the nation.

The IRON AGE

March 20, 1958 A Chilton Publication The National Metalworking Weekly

Controls: Automatic Control Methods Up Bearing Quality

A manufacturer of precision anti-friction bearings is presently employing new automatic control techniques that result in substantial improvements in bearing quality. These control techniques are used on machines which produce precision needle rollers and other type precision rollers.

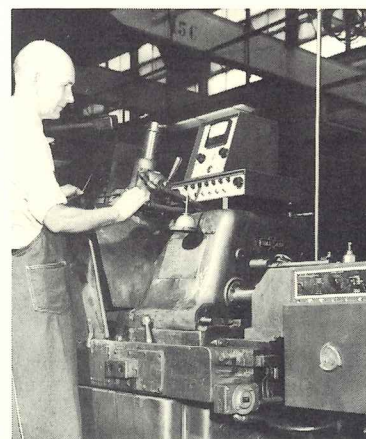
Now in use at The Torrington Co., Torrington, Conn., the new techniques were developed by Airborne Instruments Laboratory, Mineola, N. Y. They make use of a revolutionary device called an Inchworm motor. This motor, together with other equipment built by Airborne, inspects each roller as it's made. It determines whether the roller is of the necessary precision. Supplying the necessary corrective information, it actually adjusts the machine so as to correct any lack of precision in the parts it produces.

Aid Machine Operators — According to Torrington, the new techniques have relieved machine operators of a number of difficult tasks they were formerly required to perform. And they have actually resulted in a substantial improvement in the quality of the firm's bearings.

Using the new setup, the manufacturer is able to produce bearing rollers to within 50 millionths of an inch of any desired size.

Controls Grinder — The control system automatically guides the complete grinding operation on a No. 2 Cincinnati centerless grinder. This includes maintenance of part diameter to extremely close tolerances. It segregates parts into one of three grades: undersize, acceptable, or oversize.

This system utilizes the feedback control principal to accomplish automatic size control. Information, obtained from an electronic gage



The controls let this grinder work at 0.000001-in. accuracy.

measuring the diameter of the parts leaving the grinder, is converted into control signals. These are applied to the motor to correct the grinder. Machine variables, such as grinding wheel wear, and thermal expansions, are thereby automatically compensated for, resulting in accurate part size at all times.

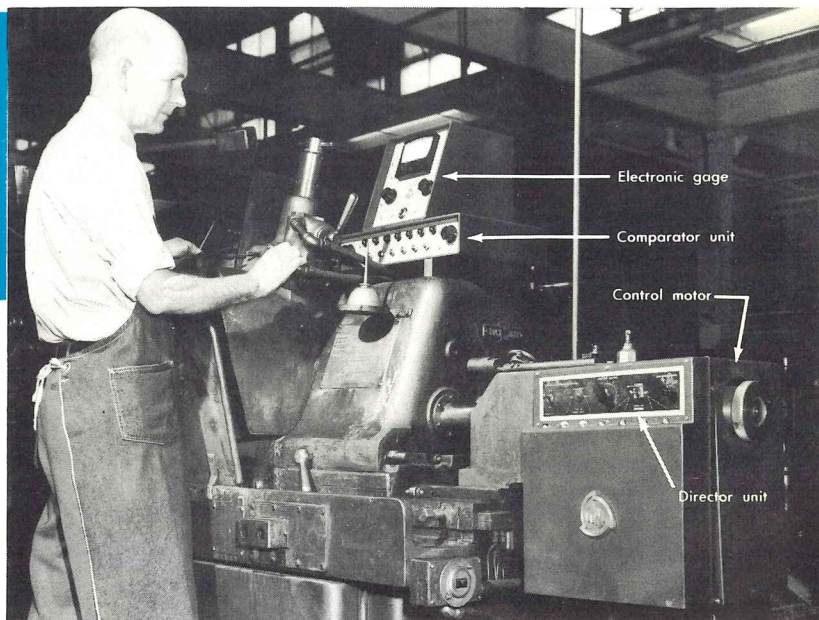
The system functions without the aid of an operator except for initial set up and wheel dressing, when required.

American Machinist

MARCH 24, 1958

Control setup . . .

that gives wheel-slide control to 5 millionths consists of linear-actuator (Inchworm) motor connected to regulating-wheel slide of a No. 2 Cincinnati centerless grinder. A Microtrol electronic gage gives feedback corrections. Except for setup and wheel dressing, no operator is required



Now, Tool Control to 5 Millionths

Micro-inch dimensional control of centerless grinders can be accomplished by replacing the leadscrew and nut with a linear-actuator motor. It's relatively simple and easy to adapt this powerful feed mechanism to machine tools

Automatic feedback for size control is the modern answer to many tolerance problems in precision machining. But what if feedback corrections are so minute that the machine can't always physically carry out the orders? Microinch correction signals, no matter how accurate, are useless if the machine is unable to respond with micro-inch movement of the tool.

The Torrington Co (Torrington, Conn) used to have this problem with the centerless grinders on its needle-bearing production line. When a corrective force was applied to a machine's leadscrew, the leadscrew "wound up" like a spring until enough force was accumulated to overcome the static friction between the regulating-wheel slide and the machine ways. Then the slide lurched forward, often by an amount greater than that required to correct part size. This "stick-slip" problem ruined a lot of high-precision bearings.

There is a minimum rate at which continuous motion of a body can be maintained. Below this rate, motion becomes incremental, consists of a series of steps. Any system's *minimum* increment of motion is dependent on a number of factors including the ratio of

break-loose force to sliding force, mechanical rigidity of the system, and the manner in which the force is applied. Torrington's problem: Reduce the minimum increment of wheel-slide motion so that the grinder could consistently respond to feedback orders in the millionth-of-an-inch range.

STICK-SLIP PROBLEM SOLVED

The company's solution was to replace the leadscrew with a linear-actuator motor, the Inchworm, Airborne Instruments Laboratory, Inc. Doing this reduced the minimum increment of slide motion by a factor of 15. The new setup produces finer bearings with tighter tolerances. There has been no sacrifice of quality control or production rates, and the automatic system relieves operators of as many fatigue problems as possible.

The linear actuator produces controlled increments of motion relative to two parts—one stationary and one fixed. There is a very rigid connection between the parts, because no leadscrew and nut, and no bearings, are in the path of force transmission. Also, the torsional factor is eliminated, and the system's response to correction signals is more positive.

This micro-inch control system is extremely rigid, yet is reversible and essentially free of backlash. It also is free of the wear-inducing lost motion found in oscillating or vibrating systems.

HOW THE ACTUATOR WORKS

The motor actuator provides precise movements of heavy loads over minute distances. Motion results from *magnetostriction*, the linear change in dimension that occurs in certain materials (such as nickel) when they are placed in a magnetic field (such as that created by current in a coil of wire). The magnetic field causes the magnetostrictive material to shorten; when the current is shut off, the material returns to its original length.

Motion is produced by shrinking the actuator's magnetostrictive armature while a hydromechanical clamp on one end of the armature is locked. This action allows one end of the armature to move. A second clamp on the other end of the armature is then locked; at the same time the first clamp is unlocked, and the magnetic field is removed, so that the armature expands. The result is that the armature moves lengthwise. This motion may be forward or backward (depending on the order in which the clamps are locked and unlocked) and closely controlled (depending on timing of current through magnetic coil).

Motion is transmitted from actuator-motor to grinder slide in this manner: The motor base is bolted to the grinder bed, and the magnetostrictive armature is attached to the regulator-wheel slide. Movement of the armature through the clamping, magnetostrictive, and unclamping actions moves the wheel slide. Wheel-slide movement can be as small as 0.000005 in. or as large as 0.000100 in., depending on the current through the coil.

HOW THE SYSTEM WORKS

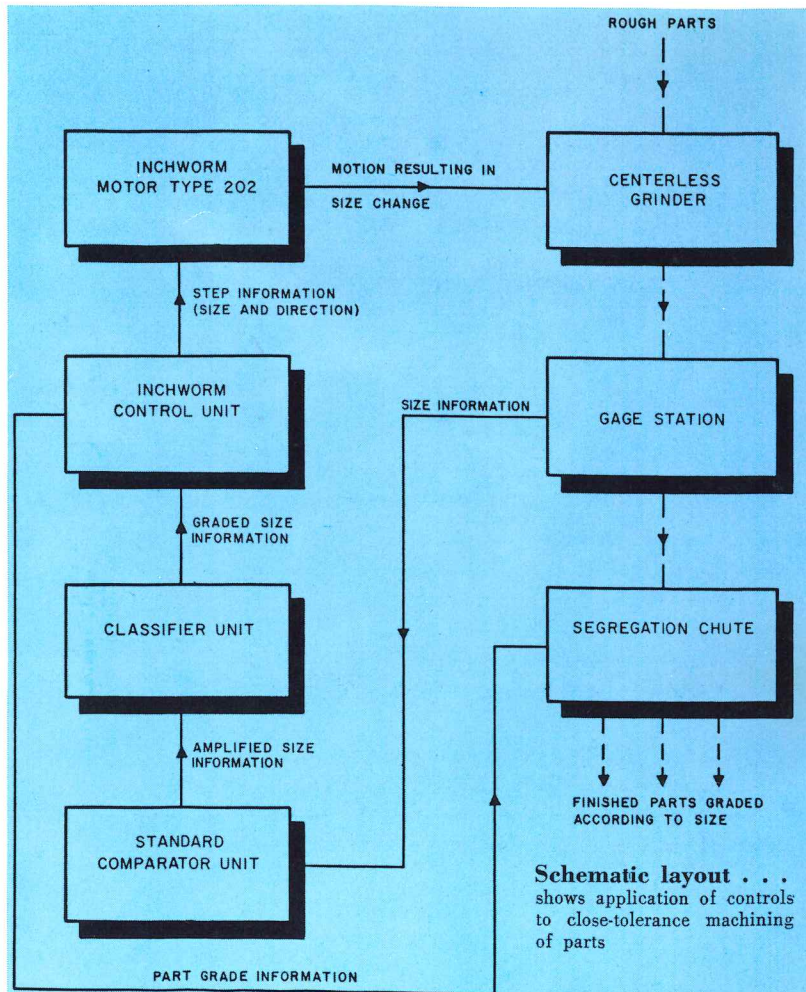
Electronic gaging equipment—a Microtrol unit, AIL—makes the grinding system automatic. This equipment accurately determines when a slide adjustment is necessary, then transmits corrective instructions to the control mechanism.

Here's how the automatic size-control system works. As parts are ground, they are gaged and the measured size is compared to the desired size. This information is transmitted to an electronic "brain" that decides whether the wheel-slide position should be corrected, in which direction, and by how much. This data is then fed to the Inchworm, which controls movement of the grinder slide.

The gaging system is selective. It won't correct for a single part that may be accidentally over-size. But if successive parts are not ground correctly, the gage's feed-control circuits average errors over several pieces, and actuate a correction cycle when these composite error-signals exceed control limits. Because delay time in averaging the size of several pieces is relatively large, the control system is stabilized to compensate only for slow rate variations, such as grinding-wheel wear, temperature changes, and trend variations in input size.

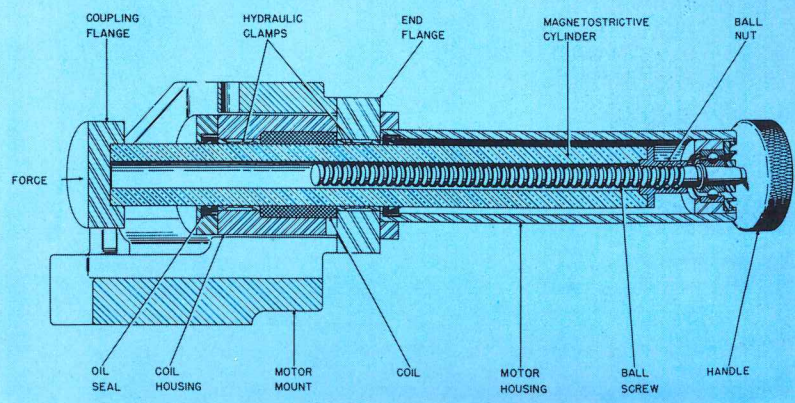
MORE OUTPUT, FEWER REJECTS

Positioning with this system is so easy and so accurate that setup and operation of centerless grinders is extremely simple, even for relatively green workers. By virtue of the Inchworm's ability to position the regulating wheel slide to an accuracy of 5 microinches, trend variations in output size have been almost completely eliminated. Thus, part tolerance is solely a function of the machine scat-



Schematic layout . . .
shows application of controls
to close-tolerance machining
of parts

INCHWORM CONTROL SYSTEM



Actuator motor . . .

(shown here in cutaway view) provides controlled micro-inch movement through magnetostrictive effect. Hydraulic clamps act in unison with armature to convert expansion and contraction of armature into forward or backward motion. Coarse feed wheel and leadscrew are only for setup purposes. In normal operation, the magnetostrictive feed over-rides the ball worm and nut, allowing the coarse feed to be used only when both clamps have been released.

ter pattern, which is usually less than 0.00005 in., even with relatively large variations in input stock size. Ever since Torrington retooled its centerless grinders, there has been a marked improvement in size control. In fact, rejects have been cut so drastically that production of usable parts has spurred considerably.

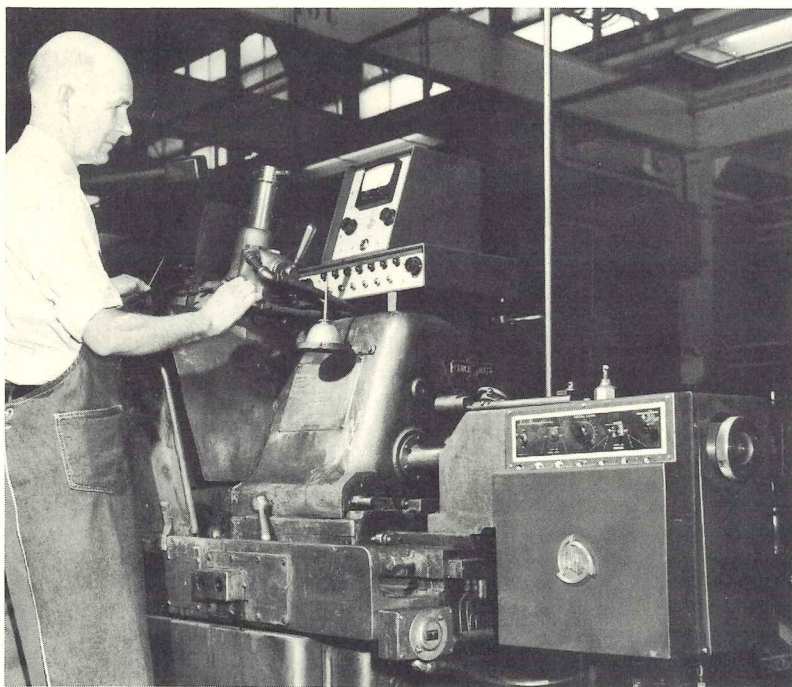
STEEL

The
Metalworking Weekly

April 7, 1958

Control to 50 Millionths

A magnetic field shrinks and swells a steel bar to produce minute increments of feed on centerless grinders. Result: The rejection of workpieces is virtually eliminated



The attachments at right and on top of the machine move the regulating wheel on this centerless grinder to adjust for size. Gages check every workpiece—tell the control when and how to correct

DRASTIC improvements in size control without any sacrifice in the speed at which parts are ground, and an absence of rejects that has boosted output of usable parts: Those advantages of a control and feed system on centerless grinders (called Inchworm) are cited by John S. Miller, plant superintendent, Torrington Co., Torrington, Conn.

The Problem — The parts are needle bearings. Each one is carried on a work rest. Adjustments are

made by moving a regulating wheel toward or away from the grinding wheel. The conventional way of doing this presents a problem:

The machine operator rotates a handwheel which is on the end of a lead screw. The force needed to start the regulating wheel is greater than that required to continue its movement; the wheel doesn't move the instant the operator begins to turn the handwheel, and the lead screw may wind up (like a spring) until enough force is accumulated

to overcome the static friction of the wheel slide. When the slide does move, it can lurch and overcorrect. Result: The adjustment is too inaccurate to control part size within tolerances.

The Solution — Here's how the Inchworm works: As each part is ground, its size is automatically measured to within a few millionths of an inch. The measurement is automatically compared with the specified size.

If adjustment is needed, the information is transmitted to a memory unit that decides whether the wheel slide should be moved, in which direction, and how much. Part size is held within 50 millionths.

No correction is made if only one part is off, but if successive parts are the wrong size, the unit makes the necessary correction. The gages detect size variations to an accuracy of 10 millionths of an inch.

How It Moves — Developed by Airborne Instruments Laboratory, Mineola, N. Y., the device uses "magnetostriction" to get precise movement of heavy loads.

Under the influence of a magnetic field, magnetostrictive material lengthens or shortens, returning to its original size when the magnetic field is removed.

Magnetostriction is combined with a pair of hydromechanical clamps. Motion is produced by shrinking the magnetostrictive armature while the clamp at one end is locked, and the one at the other end unlocked. This allows one end of the armature to move. The opposite clamp is then locked while the first one is unlocked, and the armature is expanded by removing the magnetic field. The result is a net motion of the armature. The motion may be either forward or backward, depending upon the order in which the clamps are locked and unlocked, together with the timing of the current through the magnetic coil.

(Comparison: In nature, the inchworm moves by gripping with its forefeet, hunching its body forward, then gripping with its hind feet.)

The base of the device's motor is bolted to the bed of the grinder, and the magnetostrictive armature is attached to the wheel slide. Movement of the armature through the clamps moves the wheel slide backward or forward. The minute movements can be as small as 5 millionths of an inch, or as large as 100 millionths.

FACTORY EQUIPMENT & PRODUCTION

THE TIME-SAVING DIGEST OF WHAT'S NEW IN INDUSTRY

MARCH 1958

VOL. 16, No. 3

Recirculating Furnaces Page 4

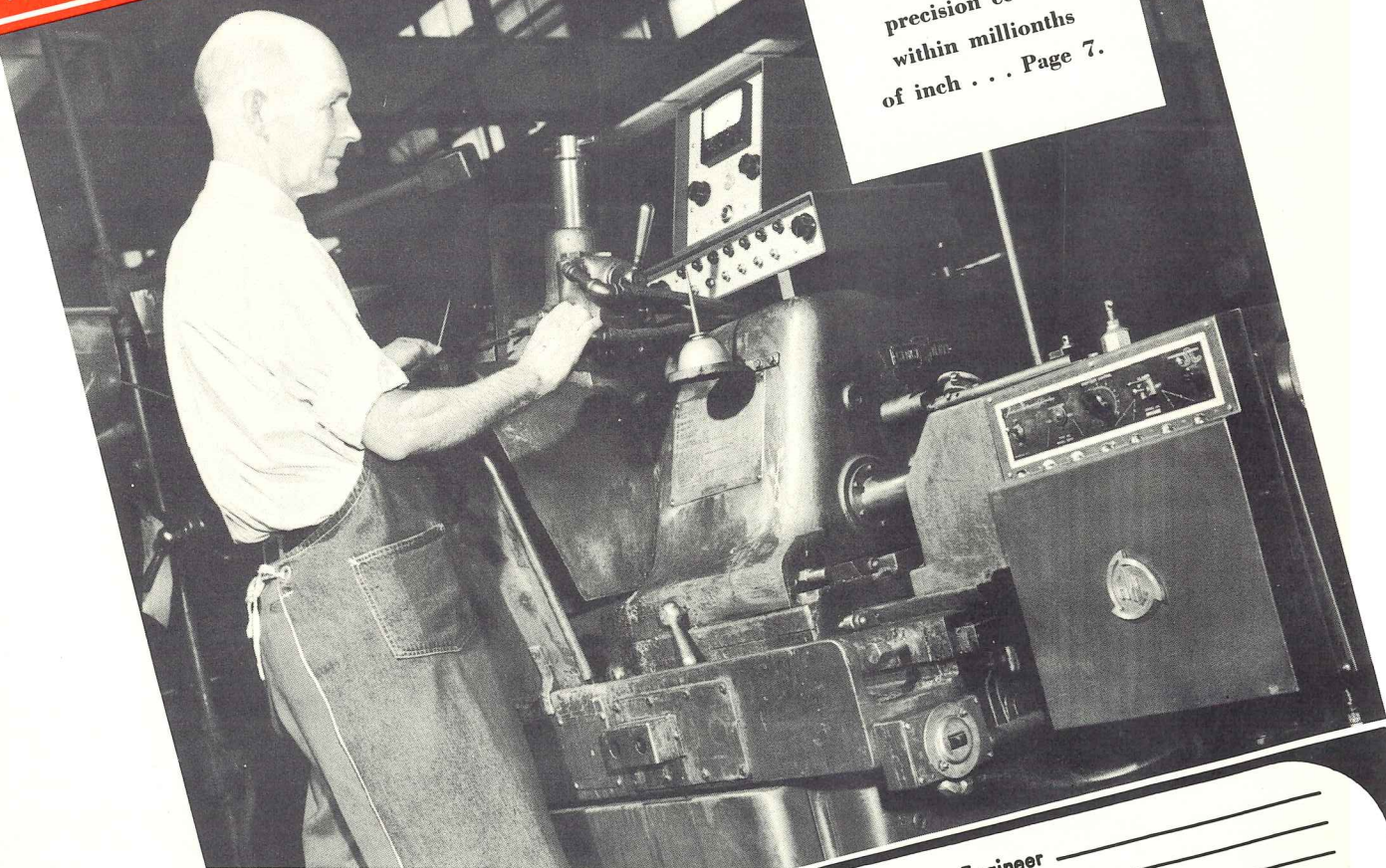
Tube Bending Ideas Page 6

Torrington uses "Inchworm" Page 7

Centralized Mist Coolant Systems Page 9

New Literature, catalogs, etc. Page 15

Torrington Uses
"INCHWORM" for
precision control
within millionths
of inch . . . Page 7.



COVER:

THE TORRINGTON COMPANY USES "INCHWORM" FOR PRECISION CONTROL WITHIN MILLIONTHS OF AN INCH

Electronic Actuator Corrects
Mechanical and Human Errors

The Torrington Company, major U.S. manufacturer of precision anti-friction bearings, has revealed the use of new automatic control techniques that result in substantial improvements in bearing quality.

These control techniques are used on the machines that produce precision needle rollers and other types of precision rollers which are used in automobiles, major home appliances, and other equipment familiar to the U.S. consumer. The new techniques, which were developed by Airborne Instruments Laboratory of Mineola, New York, use a revolutionary device called an "INCHWORM"

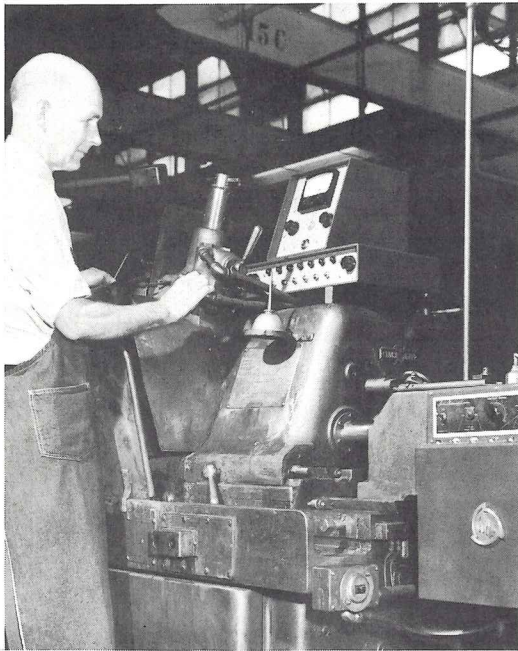
Motor". The INCHWORM*, together with other equipment built by Airborne, performs the complete function of inspecting each roller as it is made, determining whether the roller is of the necessary precision, supplying the necessary corrective information, and actually adjusting the machine so as to correct any lack of precision in the parts it produces. According to Torrington, the new techniques have relieved machine operators of a number of difficult tasks they were formerly required to perform, and have actually resulted in a substantial improvement in the quality of Torrington's bearings.

Using the new techniques, Torrington is able to produce bearing rollers to within 50 millionths of an inch (approximately one one-hundredth of the thickness of a human hair) of any desired size. With the help it has received from Airborne, Torrington expects to maintain its present position as the outstanding producer of precision anti-friction bearings. For complete case history and detailed data on "Inchworm Control System" circle number below on postcard No. 3.

the TOOL ENGINEER

APRIL 1958

Electronics Control Grinder within Millionths

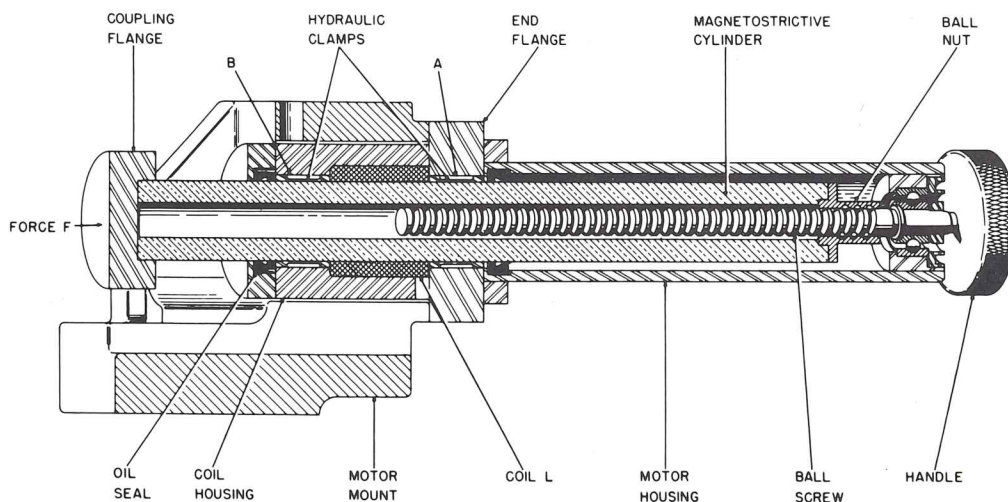


CENTERLESS GRINDER with electronic gage and precision linear actuator for adjusting grinder in accordance with signals from the feedback loop to the control system.

Precision gage and adjusting mechanism control centerless grinders at Torrington Co. to produce bearing needles within an accuracy that is consistently less than 50-millionths inch. Also, the system increases production by minimizing rejects.

Electronic gaging equipment checks each needle after grinding and determines the correction for wheel adjustment, if required. Statistical quality control is built into the gage circuit so that number of parts checked, small error or large error, cumulative trend, etc., determine the wheel-correction signal. For instance, if one part only gages slightly off size, no corrective signal is made.

The wheel adjustment mechanism utilizes an Inchworm linear motor developed by Airborne Instruments Laboratory Inc. This unusual actuator employs the action of magnetostriction which lengthens or shortens certain alloys when in an electrical field produced by a coil. Action of two clamps, working in sequence with the pulses in the coil determine the direction of linear movement, either forward or back, needed for adjustment.

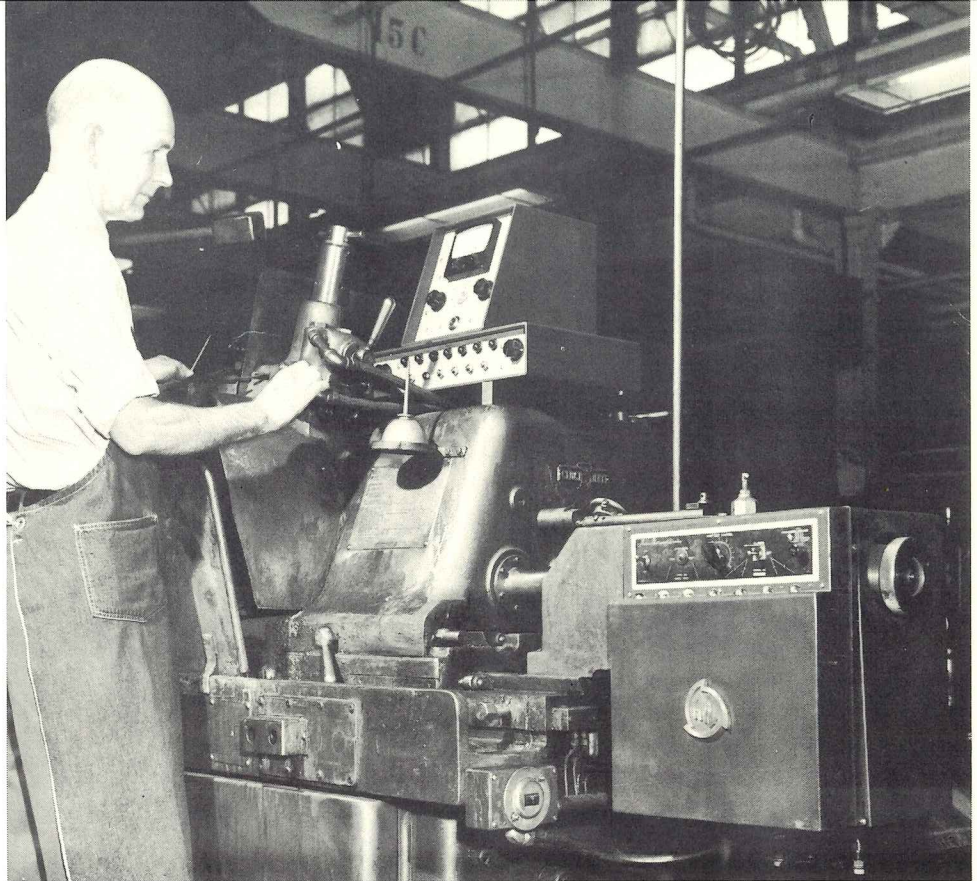


INCHWORM MOTOR derives linear motion from magnetostriction action induced by pulses of electric field from a coil. Sequence of clamp opening and closing with respect to coil energizations determines direction of motor operation.

New Techniques
For Machine Tool
Operation Provide

Precision Control Within Millionths Of An Inch

COMPLETELY AUTOMATIC system gages size variations to ten millionths of an inch. Errors are averaged over several pieces and system actuates correction when composite errors exceed control limits. Operators now devote skill to jobs requiring judgment.



AS MODERN MACHINES become more complex and intricate in their maneuvers, bearings are called upon to provide greater precision and to be lighter and smaller. Constantly rising bearing performance requirements mean closer dimensional tolerance as well as better bearing design are necessary.

At the Torrington Company in Torrington, Connecticut, new techniques are in use for centerless grinding resulting in production of bearing rollers within 50 millionths of an inch of any desired size. Moreover, the new techniques perform the complete function of inspecting each roller as it is made, determining whether it is of the necessary precision, supplying the necessary corrective information, and actually adjusting the machine to correct any lack of precision in the parts.

The techniques, developed by Airborne Instruments Laboratory of Mineola, New York, use a new device called an "Inchworm" motor. This device replaces the lead-screw of a grinder and achieves precise movements of heavy loads over minute distances.

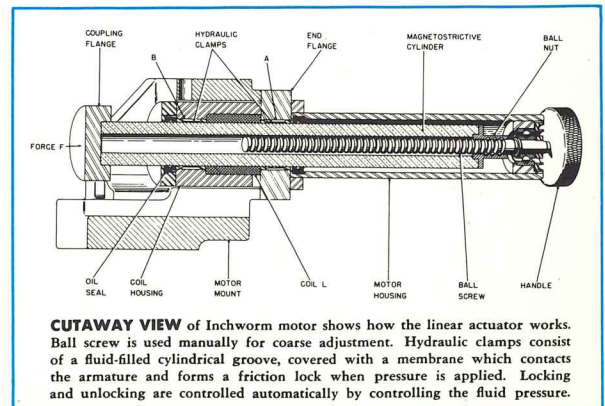
Here's how the "motor" works: The phenomenon called magnetostriction is combined in the motor with hydraulic clamps. Magnetostriction is the effect that occurs when certain alloys are subjected to a magnetic field such as that produced by an electric current flowing in a coil. Motion is produced by shrinking the magnetostrictive armature while the clamp at one end is locked and the one at the other end is unlocked. This allows one end of the armature to move. The opposite clamp is then locked while the first one is

unlocked and the armature is expanded by removing the magnetic field. The result is a net motion of the armature in the direction along its length. Motion may be either forward or backward, depending on the order in which the clamps are locked, together with the timing of the current through the coil.

The base of the motor is fastened to the bed of the grinder and the magnetostrictive armature is attached to the wheel slide. Movement of the armature moves the wheel slide backward or forward as desired. Movements can be as small as five millionths of an inch or as large as one hundred millionths.

Electronic gaging equipment automatically measures each part to within a few millionths of an inch. The measured size is compared to the desired size and an electronic "brain" decides whether the wheel slide position should be corrected, in which direction, and by how much.

With gaging, decision and action functions performed automatically, possibility of human failure is removed, size control is improved and total output is increased because of the absence of rejections.



CUTAWAY VIEW of Inchworm motor shows how the linear actuator works. Ball screw is used manually for coarse adjustment. Hydraulic clamps consist of a fluid-filled cylindrical groove, covered with a membrane which contacts the armature and forms a friction lock when pressure is applied. Locking and unlocking are controlled automatically by controlling the fluid pressure.

ELECTRIFIED INDUSTRY

APRIL
1958

Aeronautical PROCUREMENT

AIRCRAFT - MISSILES - ROCKETS - ELECTRONICS

MATERIALS & PROCESSES

Automatic Grinding System For Precision Needle Bearings

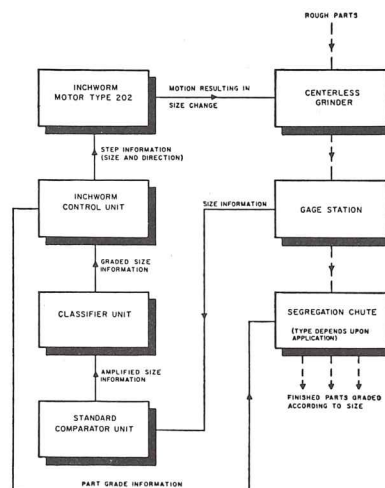
Needle bearings are produced consistently with accuracies of fifty-millionths of an inch or better, as a result of the application of a novel automatic system at the Torrington Co. The new system performs most of the jobs formerly done by the human machine operator.

Heart of the new system is an Inchworm motor—development of Airborne Instruments Laboratory—which can control machine movements down to five-millionths of an inch. The Inchworm replaces the lead screw on centerless grinders where needle bearings are ground to size and finish before assembly into finished roller bearings. Working with the Inchworm is an automatic control system that compares measured size of the bearings with desired size and tells the machine what to do when dimensions are off. After grinding, the system also segregates the bearings according to degree of accuracy.

In the manufacturing process, each bearing to be ground is carried on a work rest and positioned between two rotating wheels. The regulating wheel controls rotation of the part; the other is the grinding wheel. Size of the finished part is determined by the distance between the two wheels; the regulating wheel is moved toward or away from the grinding wheel, depending on whether the part size is to be decreased or increased.

Formerly, the operator controlled the distance between the wheels by turning a handwheel attached to a lead screw. This is difficult to control as precisely as desired. In addition, human fatigue has been an enemy of precision production.

The Inchworm uses the magnetostrictive effect and a pair of hydromechanical clamps to produce motion. This is the magnetostrictive effect: Under the influence of a magnetic field, certain materials contract; when the magnetic field is removed they return to their original length. In the Inchworm, a magnetic field shrinks a magnetostrictive armature while the clamp at one end is locked and the one at the other end unlocked. This allows one end of the armature to move. Then



INCHWORM CONTROL

the opposite clamp is locked and the first one unlocked and the magnetic field removed, permitting the armature to expand. The result is a net motion along the length of the armature, either forward or backward depending on the order in which the clamps are locked and unlocked and the timing of the current in the magnetic coil.

The base of the Inchworm motor is bolted to the bed of the grinder and the armature attached to the wheel slide. Movements of the wheel slide can be as small as five-millionths of an inch.

The electronic brain in the automatic control system has a built-in skepticism. It will not initiate a correction when only one part is the wrong size, as this may be due to an accidental occurrence that won't be repeated. But if successive parts are of the wrong size, it will make the necessary correction, depending on the size of the error and the time since the last correction. The control system also compensates for slow variations in size due to grinding wheel wear, temperature changes and trend variations in input size.

John S. Miller, superintendent of the Torrington Roller Plant, says that with the Inchworm automatic control system, Torrington has improved its size control with no loss in the speed at which parts are ground. The absence of rejections has, in fact, resulted in an increase in production of usable parts.

METLFX

Torrington 'Inchworms' to 0.000050" Grinding Accuracy

IF YOU THINK "inchworms" and "brains" belong solely to the realm of biology, you're wrong. They are control units being teamed up on Torrington Co.'s centerless grinders to give 0.000050" accuracy in grinding extremely precise Torrington needle roller bearings.

The machine used to be lead screw controlled by the operator, and accurate adjustment of the wheels was difficult and rejects high. By replacing the lead screw with a device called an Inchworm motor, the disadvantages of conventional lead-screw control methods were overcome. Then, by adding a "brain," or automatic gaging and controlling unit, production was improved more. This equipment determines when a wheel adjustment is necessary and transmits the "instructions" to the Inchworm's control mechanism.

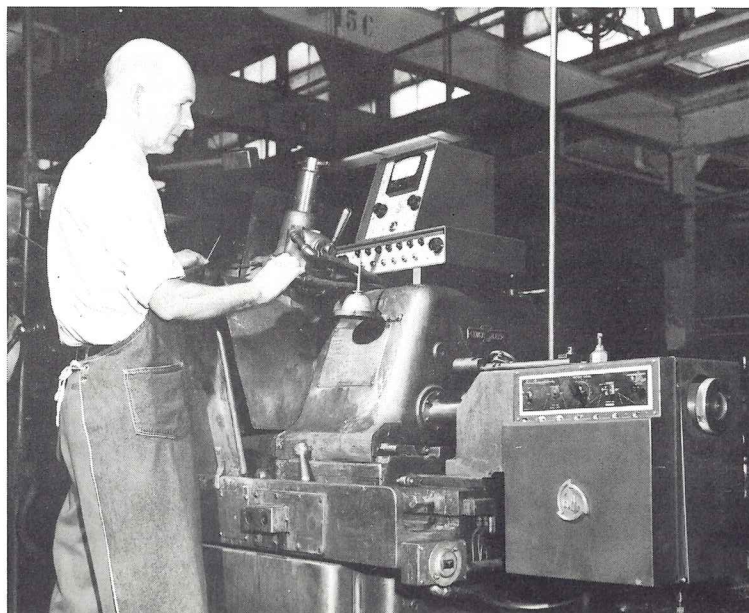
The Inchworm uses what its manufacturer, Airborne Instruments Laboratory, calls "magnetostriction" to achieve precise movements of heavy loads over minute distances. Magnetostriction is the effect that occurs when certain iron alloys are subjected to a magnetic

field. Under the influence of the magnetic field the material lengthens or shortens, returning to the original length when the magnetic field is removed.

It is combined with a pair of hydromechanical clamps in the Inchworm motor. Motion is produced by shrinking the magnetostrictive armature while the clamp at the one end is locked and the one at the other end unlocked. This allows one end of the armature to move. The opposite clamp is then locked while the first one is unlocked and the armature is expanded by removing the magnetic field. The result is a net motion of the armature in the direction along its length.

The base of the Inchworm motor is bolted to the grinder bed, and the magnetostrictive armature is attached to the wheel slide. Thus, movement of the armature through the clamps moves the wheel slide backward or forward as desired.

Without the automatic gaging equipment, the Inchworm is pushbutton-controlled by the machine operator. With the complete system, however, each part is ground, sized, and compared with the desired size. Differences in size are compensated for by the automatic "brain" if the grinder's wheel slide position should be corrected, in what direction, and by how much. The operator is now free to devote more of his skill to operations that require human judgment.



Inchworm controlled
centerless grinder,
accurate to
0.000050".

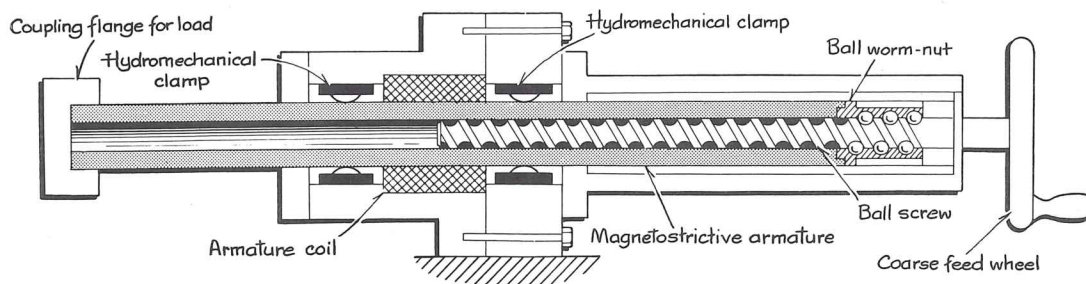


Fig. 1—Cross-sectional view of an Inchworm motor assembly shows the magnetostriuctive armature, hydromechanical clamps, and actuating coil. The hand wheel and lead screw mechanism are used for original setup and coarse feed operations. After the machine tool has been set up by the coarse feed to the correct part size, minute changes in position of the movable machine element are effected by the magnetostriuctive motor.

APPLYING MAGNETOSTRICTIVE ACTUATION FOR PRECISE LINEAR POSITIONING

Conventional methods of feeding cutting tools in metal machining setups are usually based on the use of some form of the lead screw mechanism. Inherent characteristics in translating the rotary motion of the lead screw into linear motion of the cutting tool become unseen gremlins when dimensional tolerances in the range of ± 0.000005 inches are required for precision parts. A magnetostriuctive actuator has been developed as a successor to the lead screw mechanism in such applications.

By **LAWRENCE TORN**, Chief Industrial Products Engineer, Airborne Instruments Laboratory Inc., Mineola, N. Y.

HIGH PRODUCTION of interchangeable parts on an assembly line basis requires the use of automatic machine tools capable of repetitive operations with consistent accuracy. In some industries this accuracy is defined in terms of tolerances in the range of ± 0.000005 inch. In order to achieve accuracies of this magnitude, the positioning of the machine tool cutting surfaces with respect to their work holding systems is of the utmost importance.

A typical machine tool of today consists of a massive body built to provide a rigid system for

accurate positioning and to eliminate the effect of vibration. Cutting tools are usually mounted on a heavy member which slides on accurate ways formed as a part of the machining bed. Although the slide and way system of positioning cutting surfaces is a standard method used in the machine tool industry, it possesses a characteristic known as "stick-slip" which has a detrimental effect when close control of machining tolerances is required.

In the slide and way system, it takes a greater force to start two members sliding with respect to each other than the force required to overcome a

MAGNETOSTRICTIVE ACTUATION

steady-state dynamic friction between the members. Therefore, there is a minimum rate at which continuous motion can be maintained between the members. Below this rate, the motion becomes incremental and consists of a series of jogs or steps. When a device such as a lead screw is used to actuate the slide, the rotary motion of the screw must be resolved into a linear motion to move the slide on the way. Since the force that must be exerted to start the slide moving is greater than the force required to continue movement, the slide does not begin to move the instant the screw begins to turn. Instead, the lead screw "winds up" somewhat like a spring until sufficient force is accumulated to overcome the static friction of the slide. The slide then lurches forward into motion and frequently moves by an amount greater than was required to correctly machine the part. This effect becomes more detrimental as smaller and smaller advances of the slide are required to make microinch corrections to cutting tools.

To overcome the disadvantages of the "stick-slip" motion of slides and ways, Airborne Instruments Laboratory Inc. has developed a linear actuating device known as the Inchworm motor, Fig. 1. This device replaces the conventional lead screw mechanism and meets the fundamental need in precision positioning of large mechanical loads in small, discrete, controllable steps along a linear path. It uses a physical principle called magnetostriction to achieve precise movements of heavy loads over minute distances.

Magnetostriction is the effect that occurs when certain magnetic materials are subjected to a mag-

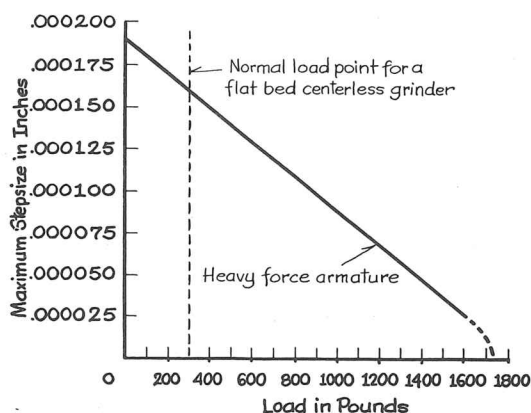


Fig. 2—Maximum step size for a particular Inchworm motor is determined by the breakloose load of the slide and the actuating coil current. The chart shown is marked for a flat bed centerless grinder which requires a breakloose force of 300 pounds and a sliding force of 220 pounds.

MAGNETOSTRICTIVE CYCLE

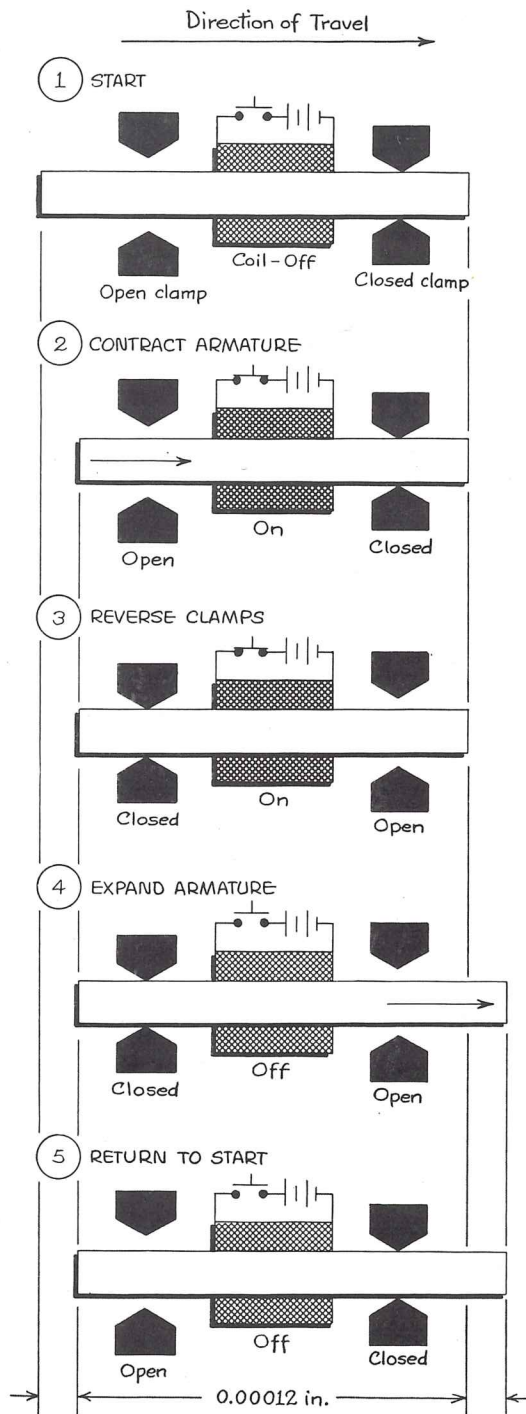


Fig. 3—One complete cycle of a magnetostrictive motor is shown diagrammatically. The actual step movement depends upon the strength of the magnetic field, the breakloose load, the type of material used in the armature, and the length of armature affected by the field.

netic field produced by current flowing through a coil surrounding the material. Under the influence of the magnetic field, the magnetostrictive material changes in length while the field is effective and returns to its original length when the field is removed. For example, a properly heat treated nickel rod can produce a magnetostrictive contraction up to 0.00003 inch per axial inch of rod length. The amount of motion is proportional to the magnetic field strength up to the point of saturation and, inversely, to the load encountered, in accordance with Hooke's Law which states that below the elastic limit the stress is directly proportional to the strain. If the rod has a four-inch long magnetic field applied to it, the theoretical maximum step size would be 0.00012 inch. In practice, the step size is approximately half that amount due to the load. Typical step sizes versus loads are shown in Fig. 2. The example marked is for a flat bed grinder which requires a breakloose force of 300 pounds and a sliding force of 220 pounds.

The Inchworm motor uses the principle of magnetostriction in combination with a pair of unique hydromechanical clamps. Micromotion is produced, Fig. 3, by locking one end of a magnetostrictive material armature with one clamp and applying a magnetic field between the hydromechanical clamps so that the armature contracts through the other unlocked clamp. The second clamp is then locked and the first clamp is unlocked allowing the armature to expand back to its original length when the magnetic field is removed. The net result is a minute motion of the armature in a direction along its length. The micromotion may be either forward or backward and depends upon the sequence in which the clamps are locked and unlocked in relation to the on-off condition of the magnetic field.

The success of this motor depends largely upon the gripping action of the clamping devices. Each clamp consists of a fluid-filled cylindrical groove covered with membrane which contacts the armature. When pressure is applied to the hydraulic fluid in the groove, the membrane deforms and presses against the armature to form a friction lock. Release of the pressure allows the membrane to retract and permits the armature to slide freely within the clamp. The clamps on the armature may be locked and unlocked at will by controlling the fluid pressures and, in actual practice, the sequencing operation of clamping and unclamping the armature is controlled automatically.

A typical magnetostrictive feed mechanism is shown in Fig. 1. Mounted on one end of the magnetostrictive armature is the movable machine element to be controlled. The two hydromechanical clamps and the armature coil are rigidly mounted to the base of the machine. In order to provide a setup and coarse feed facility, a conventional lead screw feed wheel assembly works integrally with the motor through the action of ball worm-nuts. In practice, the vernier type magnetostrictive feed device overrides the ball worm-nut and allows the coarse feed to be used only when both clamps of the fine feed mechanism are relaxed.

Magnetostrictive motors have been installed on

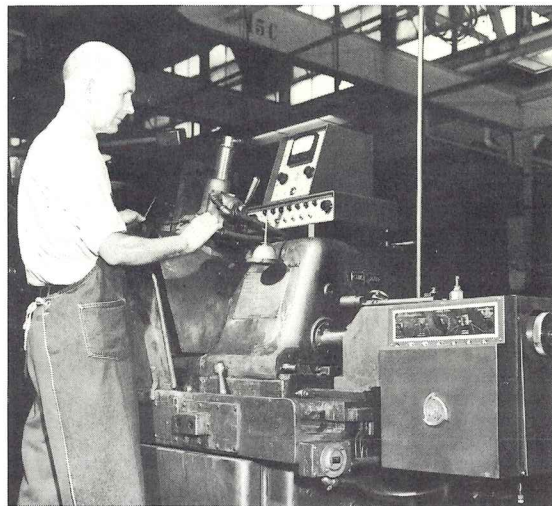


Fig. 4—An Inchworm motor installation is shown in operation on a centerless grinder at the antifriction bearing plant of Torrington Co. The motor and automatic gaging system perform some of the observation, decision, and action functions formerly manually controlled by the operator.

many machine tool applications in industry. One such installation was made on a centerless grinder line, Fig. 4, at Torrington Co., manufacturers of antifriction bearings. Applications of antifriction bearings require tolerances in the microinch range, microfinished surfaces, and extreme uniformity of every component. Maintaining close tolerances on a high-speed production line presents many problems, and Torrington engineers were interested in attaining greater precision without sacrificing output rates or quality. One operation that came under scrutiny was on the centerless grinder line where needles for bearings are ground to size and finish before assembly into finished bearings. This operation was done on a typical centerless grinder where the workpiece is carried on a workrest and positioned between a regulating wheel and a grinding wheel. The size of the part is determined by distance maintained between the two wheels. Adjustments to achieve the finished part size are made by moving the regulating wheel toward and away from the grinding wheel. The conventional method of controlling this adjustment is to move the regulating wheel by a lead screw mechanism actuated by a hand wheel under control of the operator. Since the wheel is mounted on a slide and way means, the disadvantages of "stick-slip" occurred and made control of microinch tolerances difficult.

In this installation the lead screw mechanism was removed and replaced by a magnetostrictive motor and automatic control system. The base of the motor was bolted to the bed of the grinder and the magnetostrictive armature was attached to the regulating wheel slide. Movements of the armature through the hydromechanical clamps move the regulating wheel forward and backward as desired. The minute movements through the device are as small as 0.000005 inch or as large as 0.0001 inch.

To make the grinding operation completely

MAGNETOSTRICTIVE ACTUATION

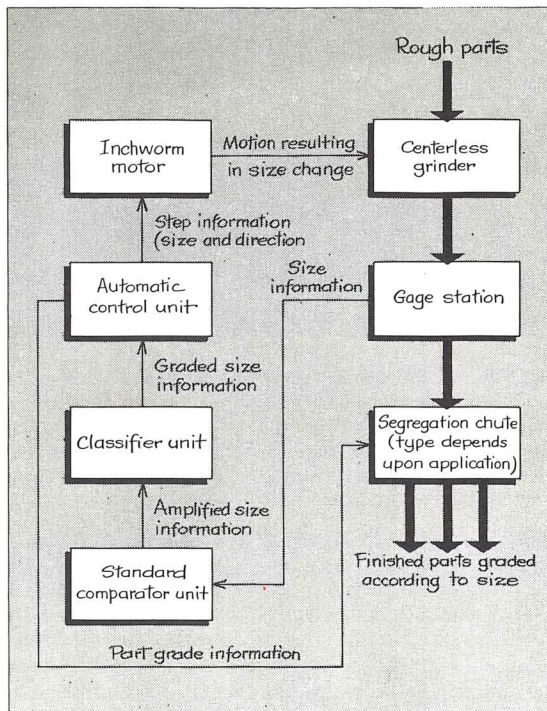


Fig. 5—Block diagram shows an automatic control system for a magnetostriuctive motor installed on a centerless grinder. Parts leaving the grinder are fed through an electronic gaging unit. Size information is fed to a comparator unit and then to a classifier unit which classifies parts into seven grades, according to the level of the signal. Relay outputs from the classifier unit provide information to the automatic control unit for regulation of the motor and correction of the grinding operation.

automatic, electronic gaging equipment was added to perform the complete function of inspecting each roller after grinding and correcting the grinding machine if successive parts are out of tolerance. Machine variables such as grinding wheel wear and thermal expansion were thereby automatically compensated for, resulting in accurate part size at all times.

The automatic control system for the motor utilizes the feedback control principle to accomplish automatic size control, Fig. 5. Finished parts leaving the grinder are guided along a track into a gaging station. An electronic gage head measures the part and converts the part size information into electrical signals. This data is compared with the desired size through a standard comparator unit which displays the part size on a meter on the face of the comparator. In addition, the signal is carried through a classifier unit for classification into seven different grades, according to the level of the signal. This unit determines if a correction should be made through the control unit to the motor. For example, if only one part is out of tolerance, no correction is made since this may result from an accidental occurrence and may not occur in subsequent parts. If successive units are off size, the unit makes the necessary correction. The applied correction depends upon the size of error, the length of time since the last correction, and whether the part is over or undersized. Since the delay time in averaging the size of several pieces is relatively large, the control system is stabilized to compensate only for slow rate variations such as grinding wheel wear, temperature changes, and trend variations in input sizes.

The automatic control system has made it possible for Torrington to produce precision parts to an accuracy that is consistently better than fifty millionths of an inch. The improvement in size control has been achieved without any sacrifice in the speed at which parts are ground.

April, 1958

NEW EQUIPMENT DIGEST

A Penton
Publication

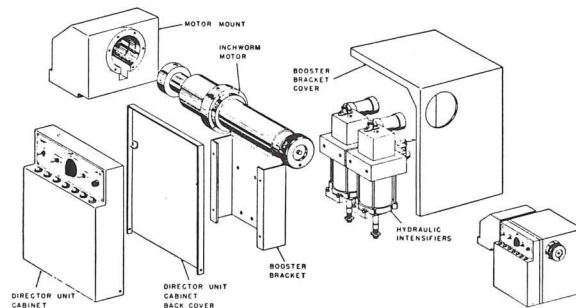
Copyright 1958 by The Penton Publishing Co.

EQUIPMENT

MATERIALS • PROCESSES • DESIGNS • APPLICATIONS • LITERATURE

AUTOMATIC CONTROL SYSTEM controls machine tool feed from 0.000005 to 0.0001 in. under load

Heart of the Inchworm automatic control system for centerless grinders and other machine tools is the Inchworm motor, or linear actuator (see NED, Au-

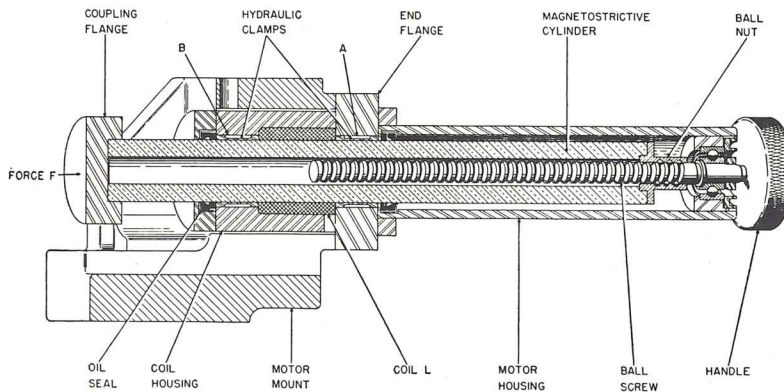


gust '56). It can be used to replace lead screws in mechanisms requiring micro-inch dimensional control from 0.000005 to 0.0001 in. The system utilizes feedback control to accomplish automatic size control. Information obtained from a Microtrol electronic gage is converted into control signals which are applied to the Inchworm motor to correct the machine.

It compensates for such machine variables as tool or wheel wear and thermal expansion. As each part is machined, its size is automatically compared to the desired size. If the two measurements differ, the equipment corrects the tool position to compensate for the error by actuating the Inchworm motor. Made by Airborne Instruments Laboratory, Inc., Dept. D, 160 Old Country Rd., Mineola, N. Y.

blue book

Controlling Grinding Feeds . . .



Cutaway view of Inchworm motor.

. . . to Micro-inches

In the Torrington Company plant, an electronic actuator corrects mechanical and human errors in the centerless grinding operation on precision anti-friction bearings before assembly.

● To improve the control of their centerless grinding action in the manufacturing of precision anti-friction bearings, the Torrington Company removed the lead screw of the grinder and replaced it with a device called an Inchworm motor. This linear actuator, a development of Airborne Instruments Laboratory, Mineola, N.Y., uses a principle called "magnetostriction" to achieve precise movements of heavy loads over minute distances.

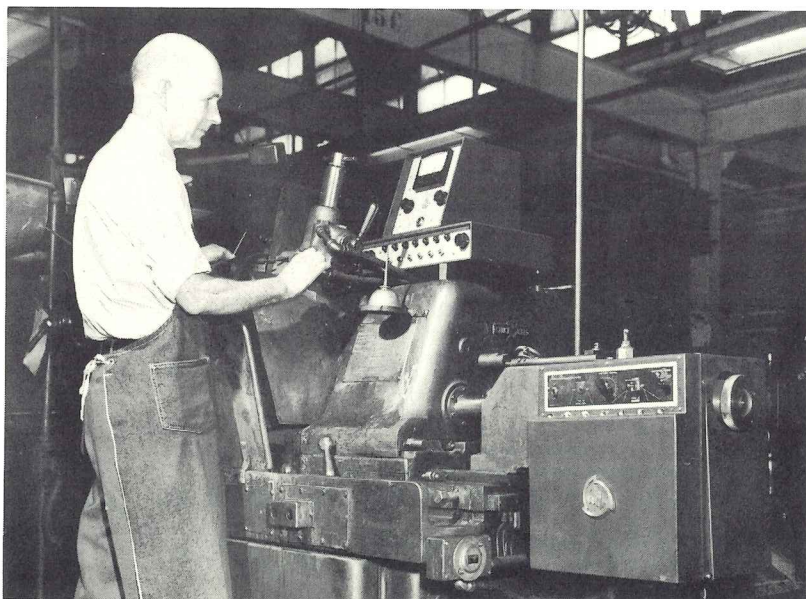
The base of the motor is bolted to the bed of the grinder, and the magnetostrictive armature is attached to the wheel slide. Thus, movement of the armature through the clamps moves the wheel slide backward or forward as desired.

The minute movements can be as small as five millionths of an inch, or as "large" as one hundred millionth.

The unit is pushbutton-controlled by the machine operator. Electronic gaging equipment accurately determines when a wheel adjustment is necessary and transmits the necessary "instructions" to the control mechanism.

The complete system operates in this way: as each part is ground, its size is automatically measured to within a few millionths of an inch, and the measured size is automatically compared to the desired size. If the measured size of the part is different from the desired size, the information is transmitted to an "electronic brain" which decides whether the wheel slide position should be corrected, in which direction, and by how much.

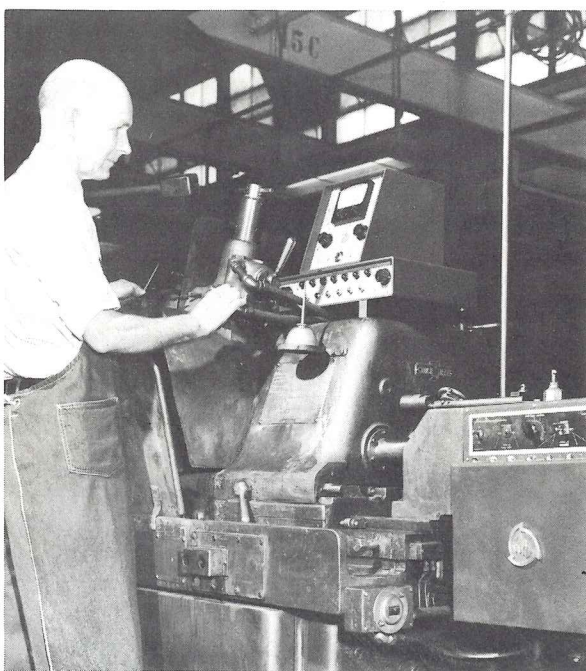
It decides that no correction should be made if only one part is the wrong size. If successive parts are of the wrong size, however, the brain will make the necessary correction. . . .



Torrington Needle Bearing plant has Inchworm installation on centerless.



Precision Control Within Microinch, Electronically



... new automatic quality control ...

The Torrington Company, major U.S. manufacturer of precision anti-friction bearings, has revealed the use of new automatic control techniques resulting in substantial improvements in bearing quality.

These control techniques are used on #2 Cincinnati centerless grinders that produce precision needle rollers and other types of precision rollers used in automobiles, major home appliances, and other equipment.

The new techniques, developed by Airborne Instruments Laboratory of Mineola, New York, use a revolutionary device called an "Inchworm Motor." The Inchworm, together with other equipment built by Airborne, performs the complete function of inspecting each roller as it is made, determining whether the roller is of the necessary precision, (undersize, acceptable, oversize), supplying the necessary corrective information, and actually adjusting the machine so as to correct any lack of precision in the parts it produces.

According to Torrington, the new techniques have relieved machine operators of a number of difficult tasks they were formerly required to perform, and have actually resulted in a substantial improvement in the quality of Torrington's bearings.

The system utilizes the feedback control principal to accomplish automatic size control. Information, obtained from a Microtrol electronic gage measuring the diameter of the parts leaving the grinder, is converted into control signals, which are applied to the Inchworm motor to correct the grinder.

Machine variables, such as grinding wheel wear, and thermal expansions, are thereby automatically compensated for, resulting in accurate part size at all times.

The system will function without the aid of an operator except for initial set up and wheel dressing, when required.

Using the new techniques, Torrington is able to produce bearing rollers an inch (approximately one one-hundredth of the thickness of a human hair) of any desired size.

For complete information write Airborne Instruments Laboratory, Inc., 160 Old Country Road, Mineola, N. Y.

SATURDAY, MARCH 22, 1958

THE TORRINGTON REGISTER

New Device Helps Torrington Co. Produce Precision Bearings

The Torrington Company, major U. S. manufacturer of precision anti-friction bearings, has revealed the use of new automatic control techniques that result in substantial improvements in bearing quality.

These control techniques are used on the machines that produce precision needle rollers and other types of precision rollers which are used in automobiles, major home appliances, and other equipment familiar to the U. S. consumer. The new techniques, which were developed by Airborne Instruments Laboratory of Mineola, New York, use a revolutionary device called an "Inchworm Motor." The Inchworm, together with other equipment built by Airborne, performs the complete function of inspecting each roller as it is made, determining whether the roller is of the necessary precision, supplying the necessary corrective information, and actually adjusting the machine so as to correct any lack of precision in the parts it produces. According to the Torrington Company, the new techniques have relieved machine operators of a number of difficult tasks they were formerly required to perform, and have actually resulted in a substantial improvement in the quality of Torrington Company's bearings.

Using the new techniques, Torrington is able to produce bearing rollers to within 50 millionth of an inch (approximately one one-hundredth of the thickness of a man hair) of any desired size. With the help it has received from Airborne, the Torrington Company expects to maintain its present position as the outstanding producer of precision anti-friction bearings.

TORRINGTON CLAIMS NEW TECHNIQUES

The Tribune's Special Service.

TORRINGTON, Conn — The Torrington Co., major manufacturer of precision and anti-friction bearings, has announced the use of automatic control techniques claimed to result in a substantial improvement in bearing quality.

Torrington, one of whose operations is its Bantam Bearings Division in South Bend, said the control techniques are used on machines that produce precision needle rollers and other types of precision rollers for automobiles, major home appliances and other equipment.

Developed by Airborne Instruments Laboratory, Mineola, N.Y., the method employs a device called an Inchworm motor. The Inchworm, with other equipment built by Airborne, is said to perform the complete function of inspecting each roller as it is made, and adjusting the machine to correct any lack of precision in the parts it produces.

GRINDING OPERATIONS ARE CONTROLLED TO WITHIN MILLIONTHS *With Electronic Actuator*

THE VERY NATURE of anti-friction bearing applications is defined in terms of tolerances in "tenths", micro-finished surfaces, and extreme uniformity of every component. The problems of bearing design, materials, and mass manufacturing have progressively mounted in this age of high-powered automobile engines, jet airplanes, guided missiles, electronic computers, and nuclear reactors.

More complex gadgets to perform more intricate maneuvers, confined within constantly shrinking space and weight allowances are the order of the day. The same bearing, or even a smaller one, is expected to carry a much higher load. About the only way to keep up with these constantly rising bearing performance requirements is to further refine the bearing and build it to still closer tolerances.

The Torrington Company, Torrington, Conn., has long been an outstanding leader in the manufacture of precision anti-friction bearings. Maintaining close tolerance specifications on a high-speed assembly-line operation presents many problems, but the company not only has met each new demand for closer precision, but, in most cases, bettered them by a satisfying margin.

One of the significant problems coinciding with the closing down of tolerances is the matter of human fatigue which, of course, is cumulative as the work day progresses. Torrington's dual objective then is to attain even greater precision in its bearing, without reducing production rates, and in ways that would relieve the machine operator of as many of the fatigue-producing factors as feasible.

One area to come under scrutiny was the centerless grinder line where needle bearings are ground to size and finish before assembly into finished needle roller bearings.

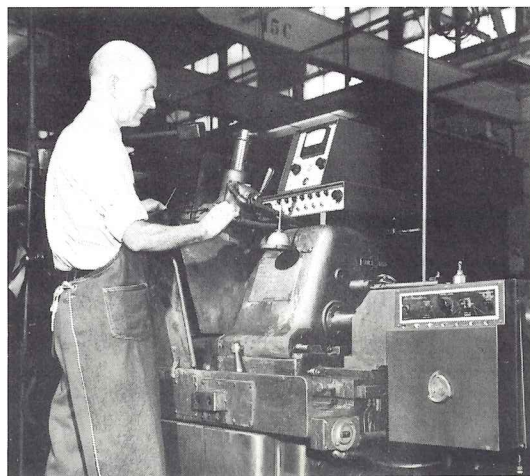
Each needle bearing to be ground is carried on a work rest and positioned between two rotating wheels — a regulating wheel which controls the rotation of the part, and a grinding wheel which does the actual grinding. The size of the finished part is determined by the distance between the two wheels. Adjustments to achieve the desired part size are made by moving the regulating wheel toward or away from the grinding wheel. The conventional method of moving the regulating wheel is for

the machine operator to rotate a hand wheel on the end of a lead screw.

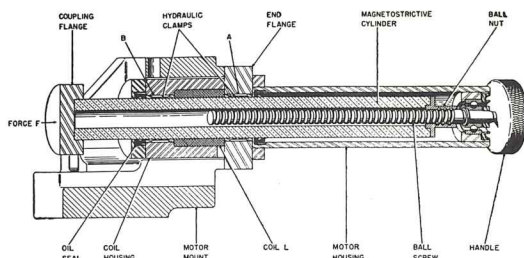
When the regulating wheel slide is stationary, the force that must be exerted to start its movement is greater than the force required to continue the movement; the result is that the wheel slide does not move immediately as the operator begins to turn the hand wheel. Instead, the lead-screw "winds up" somewhat like a spring, until sufficient force has been accumulated to overcome the static friction of the wheel slide; then the slide lurches forward, frequently by an amount greater than the desired correction. This stick-slip characteristic adds to the difficulty of making precise adjustments to control the part size.

These disadvantages of the conventional lead-screw method of controlling the grinder were overcome at Torrington by removing the lead screw and replacing it with an Inchworm Motor, a development of Airborne Instruments Laboratory. The Inchworm uses a novel physical principle called "magnetostriction" to achieve precise movements of heavy loads over minute distances.

The base of the Inchworm Motor is bolted to the bed of the grinder, and the magnetostrictive armature is attached to the wheel slide. Thus, movement of the armature through the clamps moves the wheel slide backward or forward as desired. The minute



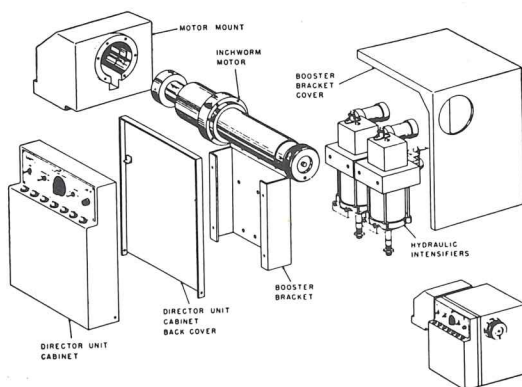
Inchworm installation at Torrington's needle bearing plant controls centerless grinding to consistent accuracy, within millionths.



Cutaway view of the Inchworm motor, a linear actuator which replaces the lead screw in mechanisms requiring micro-inch dimensional controls.

movements can be as small as 0.000005", or as large as 0.0001". In its most elementary application, the Inchworm is pushbutton-controlled by the machine operator approximately every 15 sec on roughing cuts, less frequently on finish cuts. To make the operation completely automatic, electronic gaging equipment was added, capable of accurately determining when a wheel adjustment was necessary and transmitting the necessary instructions to the control mechanism. Airborne has developed standard units for this purpose.

As each part is ground, its size is automatically measured to within a few millionths of an inch, and the *measured* size is automatically compared to the *desired* size. The information is transmitted to an "electronic brain" which weighs a great many factors and makes its decision instantaneously. For example, it decides that no correction should be made if only one part is the wrong size, since this may possibly be the result of an accidental occurrence that will not be repeated on subsequent parts. If successive parts are of the wrong size, however, the brain will make the necessary correction. The distance the wheel slide must be moved, and the direction, are dependent upon factors such as the size of the error in part size, the length of time since the last previous correction, and whether the part is under-size or over-size.



Exploded view of basic Inchworm assembly as applied to centerless grinders. Inchworm system corrects both mechanical and human errors.

HOW THE INCHWORM WORKS

MAGNETOSTRICTION IS THE EFFECT THAT OCCURS when certain alloys are subjected to a magnetic field — the magnetostrictive material lengthens or shortens, returning to the original length when the magnetic field is removed by turning off the current in the coil of wire.

On the Inchworm magnetostriction is combined with a pair of hydromechanical clamps. Motion is produced by shrinking the magnetostrictive armature while the clamp at one end is locked and the one at the other end unlocked. This allows one end of the armature to move. The opposite clamp is then locked while the first one is unlocked and the armature is expanded by removing the magnetic field. The result is a net longitudinal motion of the armature. The motion may be either forward or backward, depending upon the order in which the clamps are locked and unlocked, together with the timing of the current through the magnetic coil.

The overall effect is very similar to that by which the Inchworm's familiar green namesake progresses along a tree branch, gripping the branch with its forefeet, hunching its body forward, then gripping with the hindfeet, hunching forward again, and so on. Unlike the green inchworm, the Inchworm can "crawl" backward as well as forward.

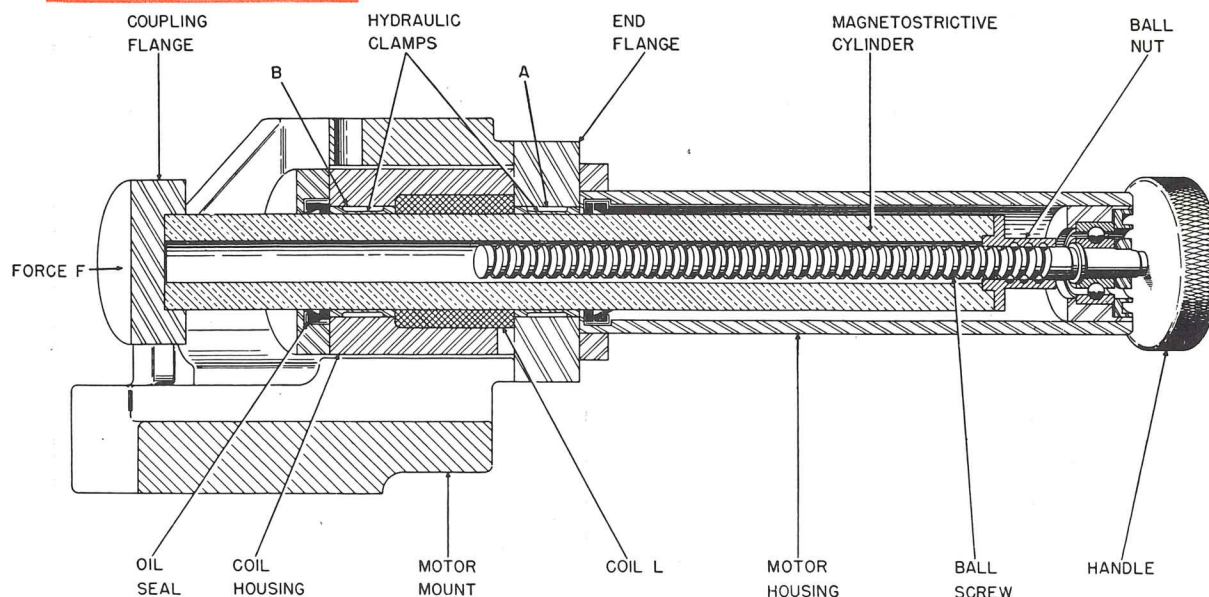
The gage feed control circuits, which average errors over several pieces, actuate a "correction" cycle when composite error signals exceed control limits. A step of large size is automatically provided in response to gross errors; gradual error trends result in smaller steps. Since delay time in averaging the size of several pieces is relatively large, the control system is stabilized to compensate only for slow rate variations such as grinding wheel wear, temperature changes, and trend variations in input size.

The complete automatic control system performs most of the observation, decision, and action functions that were previously performed by the grinder operator. He can now devote more of his skill to operations that require human judgment.

The Inchworm automatic control system has made it possible for Torrington to produce precision parts such as needle bearings, which have almost unlimited applications, to an accuracy that is consistently greater than ever before obtained (typically 0.00005" or better.) According to John S. Miller, Superintendent of the Torrington Roller Plant, an improvement in size control has been achieved without any sacrifice in the speed at which parts are ground. In fact, the absence of rejections that used to occur has resulted in an increase in total output of usable parts.

end

SYSTEMS DESIGN



INCHWORM MOTOR

Magnetostriuctive Forces Actuate Linear Feed Mechanism

The inchworm motor, a linear actuator developed by Airborne Instruments Laboratory of Mineola, New York, is a powerful feed mechanism that is accurately controllable in micrometers. The design employs the magnetostriction phenomenon—the change in dimension that occurs in certain materials when they are placed in a magnetic field. For example, a properly heat-treated nickel rod can produce a magnetostriuctive change up to 0.00003 inch per axial inch of rod length. The total amount of motion obtained is proportional to the magnetic field strength up to the point of saturation and, inversely, to the resistive load in accordance with Hook's law—the proportionality of stress to strain.

In the inchworm design, the armature of the motor shrinks under the influence of an electromagnetic field, snapping back to the original size when the magnetic field is de-energized. A pair of clamps act together with the armature to convert the expansion and contraction into forward or backward motion reversing on demand without backlash.

Because the inchworm motor concept can control the movement of large forces from 0.000005 to 0.0001 inch, a logical application is in the machine tool field replacing lead screws in centerless grinders for precisely finished machine components. It recently found its first large-scale application in this field when the Torrington Company of Torrington, Conn., applied the inchworm motor to equipment in their needle bearing plant.

FIG 1—Cross-section of one inchworm motor design shows how a magnetostriuctive nickel rod is supported in a pair of co-axial clamps. A and B. These clamps are spaced to provide a maximum step size. Coil L generates a magnetic field in the rod. For movement to the left the system is sequenced so that clamp A is opened, the coil is energized shrinking the nickel bar in the magnetic field, clamp A is closed, clamp B is opened, the coil is de-energized allowing the prestressed nickel bar to expand against the force F and, finally, clamp B is again closed leaving both clamps on in the rest position. A similar sequence in reverse order causes movement in the opposite direction.

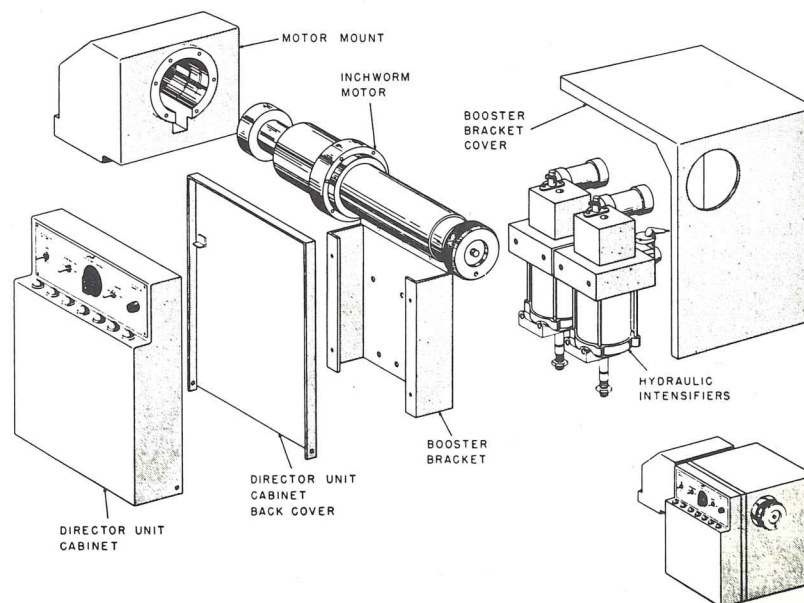


FIG 2—Exploded perspective showing the arrangement of the basic inchworm motor and its controls.

Torrington manufactures precision anti-friction bearings for use in automobiles, airplanes, precision instruments, electronic computers and other precise applications. Maintaining close tolerance specifications on a high-speed assembly line operation presents their production engineers with many prob-

lems, one of which involves the matter of human fatigue, cumulative as the work day progresses.

Torrington's needle bearings are ground to size and finish on centerless grinders. Each needle bearing is carried on a work rest and positioned between two rotating wheels, a regu-

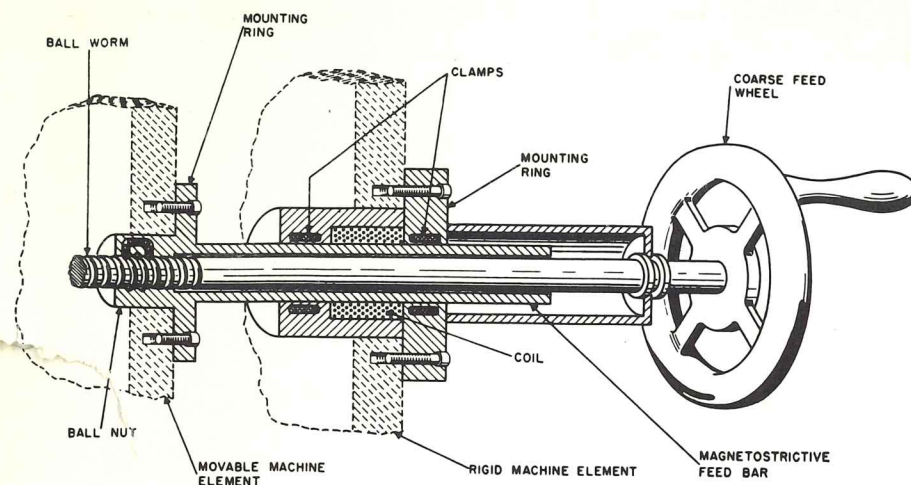


FIG 4—Functional schematic of inchworm motor set up in conjunction with a coarse feed wheel.

lating wheel that controls the rotation of the part and a grinding wheel which does the actual grinding.

The distance between the two wheels determines the size of the finished part. Adjustments in part size are made by moving the regulating wheel toward or away from the grinding wheel, depending upon whether part size is to be decreased or increased. The conventional method of moving the regulating wheel and thus controlling the size of the finished part is for the machine operator to rotate a hand wheel on the end of a lead screw. As the lead screw rotates, the regulating wheel slides forward or backward, depending upon the direction the lead screw is rotated and by an amount determined by how far it is turned.

When the regulating wheel slide is stationary, the force that must be exerted to start its movement is greater than the the force required to continue

the movement—the force necessary to overcome the inertia of the system. During this time, the lead screw winds up somewhat like a spring until sufficient force has been accumulated to overcome the static friction of the system. Then, the slide lurches forward, frequently by an amount greater than the desired correction.

The inchworm motor overcomes this disadvantage of the lead screw method of controlling grinders. The magnetostriction in the inchworm operates in juxtaposition with a pair of hydromechanical clamps. Motion is produced by shrinking the magnetostrictive armature while the clamp at one end is locked and the one at the other end unlocked. This allows one end of the armature to move. The opposite clamp is then locked while the first one is unlocked and the armature is expanded by removing the magnetic field. The result is a net motion of the armature

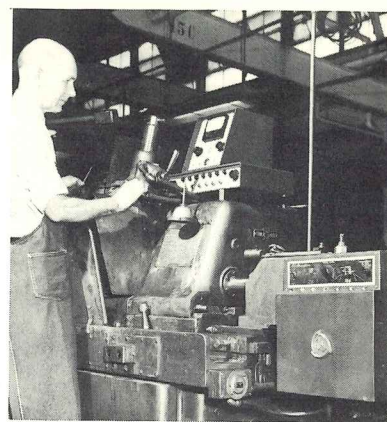


FIG 3—Inchworm installation at Torrington needle bearing plant controls centerless grinding operations to consistent accuracy within millionths of an inch. Linear actuator replaces the lead screw in mechanisms requiring micro-inch dimensional controls.

in the direction along its length. Motion may be either forward or backward depending upon the order in which the clamps are locked and unlocked together with the timing of the current through the magnetic coil that surrounds the magnetostrictive material. The over-all effect is very similar to that by which the inchworm's familiar green namesake progresses along a tree branch, gripping the branch with its forefeet, hunching its body forward then gripping with the hind feet.

To make the operation completely automatic, designers at Airborne Instruments Laboratory, Inc., added electronic gaging equipment capable of determining when the wheel adjustment was necessary and transmitting the instructions to the control mechanism. This system is now a standard unit for applications of this type. Demonstration installations of the inchworm motor have consistently reproduced an accuracy of ± 0.000005 inch under machine load conditions requiring a break-loose force of 300 pounds and a sliding force of about 220 pounds. This type of accuracy is based on maintaining a very rigid connection between the two moving parts, one of which is stationary because there are no lead screws, split nuts or bearings in the part of the force transmission. In addition, the elimination of the torsional factor in conventional systems permits the system to be extremely rigid, yet reversible and essentially free of backlash and lost motions encountered in oscillatory or vibrating systems. The inchworm automatic control system has made it possible for Torrington to produce precision parts to an accuracy that is approximately 50 millionths of an inch or better. According to John S. Miller, Superintendent of the Torrington Roller Plant, an improvement in size control has been achieved without any sacrifice in the speed at which parts are ground.

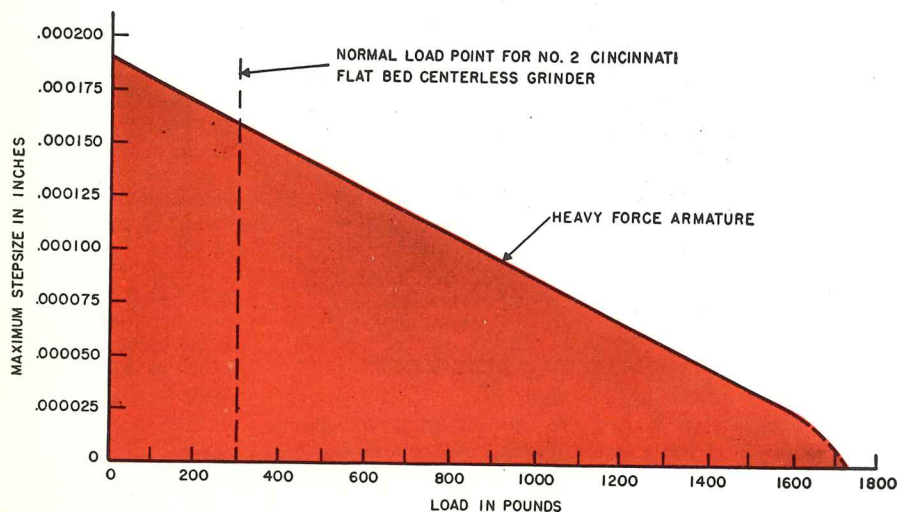


FIG 5—Inchworm motor load characteristics step size versus load.



Received May 2, 1958 L.M.S.

Postage
Will Be Paid
by
Addressee

No
Postage Stamp
Necessary
If Mailed in the
United States

B U S I N E S S R E P L Y C A R D

FIRST CLASS PERMIT NO. 136, MINEOLA, N. Y.

SALES DEPARTMENT

AIRBORNE INSTRUMENTS LABORATORY, INC.

1345 NEW YORK AVENUE

HUNTINGTON STATION, N. Y.



Company_____

Street_____

City & State_____

Name_____ **Position**_____

I am interested in the following equipment:

- ☐ **MICROtrol Type 150 (Automatic Size Control Equipment for Plunge Grinders)**
- ☐ **MICROtrol Type 160 (General Purpose Electronic Gaging and Control Equipment)**
- ☐ **MICROtrol Type 170 (Transistorized, Portable Comparator Equipment)**
- ☐ **Inchworm Motor Type 202 (Control Equipment for Centerless Grinders)**
- ☐ **Inchworm Motor Type 203 (Miniature)**

☐ **Please send literature** ☐ **Please have your representative call**

